MECHANICAL PROOF TESTING IN CELL PROCESSING

C. P. Chen**
M. H. Leipold***
R. G. Ross****

Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive, Pasadena, California 91109

ABSTRACT

Fracture mechanics test methods are applied to evaluate the proof test characteristics of silicon Cz wafers.

The results indicate that the strength distribution of silicon wafers is truncated by proof testing and no subcritical crack growth in silicon is observed during proof loading. Mechanical proof testing appears to be an effective method to eliminate weak samples before cell processing.

INTRODUCTION

Cracking of silicon solar cells has been found to be one of the major factors controlling cell production yield. Silicon is a brittle material. Cracking of silicon cells results from the extension of a critical pre-existing flaw which was generated during ingot wafering, cell processing and handling. The entire problem of cost trade-offs of the FSA project or the terrestrial cell manufacturing will be influenced by the cell yield and cell rejection rate.

In a recent paper (1) on the effects of production processes on the fracture strength of silicon solar cells, Weibull statistical analysis was used to describe the strength data distribution. This involves plotting fracture probability as function of fracture strength of silicon solar cells for several production processes. A long tail at the low-stress portion of the strength distribution curve was found for most types of samples. The wafers or cells in the low-strength distribution are likely to be fractured during subsequent cell processing and handling. Such fractures result in costs associated with earlier processing and potential destruction of other good wafers. The result indicated that a proof testing would be desirable to eliminate those weak samples before the subsequent cracking occurs.

The objectives of this study are to demonstrate that all weak samples can be eliminated by a mechanical proof testing, to evaluate the possible subcritical crack growth during the proof loading and to determine the critical flaw size at several proof testing levels.

TEST METHOD

Biaxial flexure strength testing (2,3) on chemical polished (100) silicon Cz wafers, 2 inch diameter*, was used to evaluate the proof testing characteristics of silicon. Weibull statistical analysis was utilized to describe the measured fracture strength of the initial distribution as well as the distribution after proof testing at several levels. Proof testing was performed at 215, 260 and 310 MPa which are equivalent to the 15%, 30% and 50% fracture probability, respectively, of the initial stress distribution. Weibull distribution of proof testing results is shown in Figure 1.

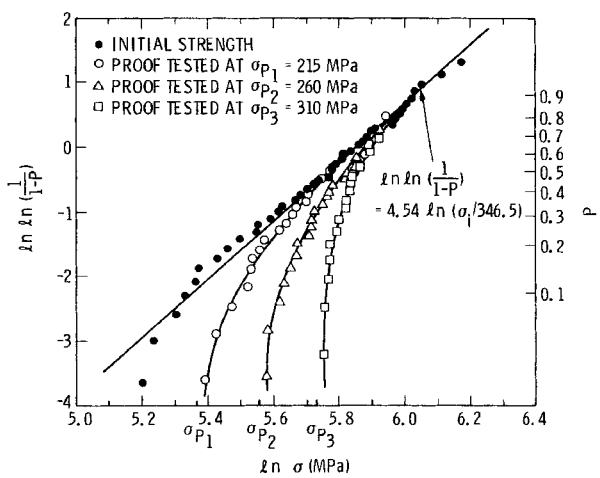

Fig. 1. Weibull Distribution of Proof Testing Results of Silicon Wafers

A dynamic fatigue test method for brittle materials (4) was used to evaluate the possible subcritical crack growth during the proof testing. The biaxial strength of silicon wafers as a function of loading rate was determined and can be expressed by an equation of the form:

$$\ln\sigma = \frac{1}{N+1} \ln\dot{\sigma} + Jo$$

*Supplied by Spectrolab, Inc. CA.

** Member of the Technical Staff, Applied Mechanics Technology Section.
*** Manager, Processing Development, Flat-Plate Solar Array Project.
****Manager, Reliability and Engineering Sciences, Flat-Plate Solar Array Project, Energy Technology Section.

This paper presents the results of one phase of research conducted within Applied Mechanics Technology Section of the Jet Propulsion Laboratory, California Institute of Technology, for the U.S. Department of Energy, through agreement with the National Aeronautics and Space Administration.

Proceedings of the 17th IEEE Photovoltaic Specialists Conference
Kissimmee, Florida, May 1-4, 1984, pp. 1384-1385.

where $\dot{\sigma}$ is stress rate
N is the stress rate sensitivity of the strength of the material
Jo is a material constant
σ is the stress of interest

Finally, the critical flaw sizes at the proof testing can be calculated by an available fracture mechanics equation, as follows:

$$K_{IC} = Y\sigma_p \sqrt{a_p}$$

where a_p is the critical flaw size

σ_p is the proof testing stress level

Y is the flaw shape factor

K_{IC} is the fracture toughness of silicon

RESULTS

The test results were summarized as follows:

1. Biaxial strength distribution of silicon wafers is described by a Weibull equation as

$$P = 1 - \exp\left[-\int_A \left(\frac{\sigma}{\sigma_o}\right)^m dA\right]$$

where P = fracture probability

σ = stress of interest

A = the surface area under stress where crack propagation can result in final fracture of silicon sample

σ_o = material constant, it was found that

σ_o = 346.5 MPa

m = Weibull modules which relates to the scatter of the strength data. The test results showed that m = 4.54.

2. Dynamic fatigue test results indicated that subcritical crack growth in silicon during proof loading was not observed. The loading rate sensitivity factor (N) was found to be infinity.

3. The maximum critical flaw size for silicon wafers as received before proof testing is

$$a_i = 6.5 \times 10^{-6} m$$

The critical flaw sizes after the indicated proof testing levels are calculated to be:

$$a_1 = 4.6 \times 10^{-6} m \quad @ \ 215 \text{ MPa}$$

$$a_2 = 3.1 \times 10^{-6} m \quad @ \ 260 \text{ MPa}$$

$$a_3 = 2.1 \times 10^{-6} m \quad @ \ 310 \text{ MPa}$$

4. The strength distribution of silicon wafers was truncated by proof testing. Mechanical proof testing appears to be an effective method to elminate weak samples in the cell processing.

REFERENCES

1. C. P. Chen, E. L. Royal and H. Klink, "Effects of Production Processes on the Fracture Strength of Silicon Solar Cells," Proceedings of the 14th IEEE Photovoltaic Specialists Conference, P. 929-934, January 1980.

2. C. P. Chen, "Fracture Strength of Silicon Solar Cells," JPL Publication 79-102, DOE/JPL LSA Project Report 5101-137, Oct. 15, 1979.

3. ASTM F394-74T, "Tentative Test Method for Biaxial Flexure Strength (Modules of Rupture) of Ceramic Substrates.

4. J. E. Ritter, Jr., and J. N. Humenik, "Static and Dynamic Fatigue of Polycrystaline Alumina," J. of Materials Science, 14, P. 626-632, 1979.